A multidisciplinary team building method based on competency modelling in design project management.

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Abstract. This research aims to develop a new team building method based on competency modelling in the field of project management. This method is divided into three main stages. First, a competency matrix based on a task-actor compatibility indicator helps to characterise the competency levels. Second, we apply a clustering algorithm in order to reduce the problem complexity and favour the employees' expertise. The clustering algorithm will decompose large sets of tasks and actors into smaller task groups related to different actor groups. It facilitates the project leaders to organise the actors into teams. Finally, the proposed task assignment model incorporates a learning curve in order to take the competency dynamics into account. Our computational experiments suggest that incorporating a clustering algorithm as a step of the method results in preserving expertise and thus helps project managers to find better tradeoffs between project cost (short term goal) and competency dynamics (long term goal).

Keywords: team building, multidisciplinary team, clustering algorithm, task assignment, mathematical programming, product design project, competency.

1. Introduction

Design teams are multidisciplinary groups composed of members representing many engineering disciplines. Specialists from various disciplines (e.g. electronics, thermodynamics, manufacturing, mechanics, image processing, and optics) are gathered to develop a new product.

The project groups include formal but temporary assignments to groups, committees, and special projects. After a project has been completed, project group members return to their routine activities or go to another temporary project group.

The research works concerning team building in the context of design projects share some common characteristics: multidisciplinary tasks and designers, a large quantity of tasks in a project, a large number of designers, and a task-designer assignment problem. To reduce the project complexity, one way to build teams is to decompose large, complex design processes and project organisation into a set of smaller task groups corresponding to different teams. According to Chen and Li [1], a team should consist of multiple

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designers with different technical backgrounds and expertise, contributing to a design task as part of the whole design project. It is expected that essentially, a team model should represent the interdependence between teams such that each team has its own objective and constraints for a distributed design problem.

To reach our research goal, a task-designer assignment model is required, assigning the right task to the right team designer. Task assignment is based on the characteristics of tasks and designers. In a task assignment problem, project managers always have to make a tradeoff between the preserving of intra-domain expertise and the development of extra-domain expertise. The problems of high rate of workforce turnover and competency deterioration can be stimulating factors for project managers to assign tasks to team members in order to increase their capabilities. There is a need to better integrate competency modelling in team building in order to take competency dynamics into account.

In this paper, we develop a general framework that is applicable in product design projects for building project teams. This framework is organised into three stages: building of a task-actor compatibility matrix (that is, a competency matrix), clustering of the competency matrix and competency-based task assignment. The first stage aims to compute compatibility indicators between tasks and actors. The second stage clusters the elements of the compatibility matrix in order to obtain task-actor families. In the last stage, cost consideration and competency dynamics are considered simultaneously in the competency-based task assignment.

The organisation of this paper is as follows: Section 2 reviews team building literature. Section 3 proposes a new approach to the multidisciplinary team building method. Section 4 gives a mathematical formulation for task assignment. As an illustration, a simple team building problem is formulated and solved upon the team building method described in section 5. Section 6 summarises the paper.

2. Review of team building literature

Several team building applications exist in research literature concerning different engineering management issues, such as design project management, production management and construction management. In this section, we focus on the team building applications in the field of new product design project management.

There are different project management issues close to team building. Authors have dealt with task sequencing and grouping by means of DSM and sequencing algorithms [2],[3],[4],[5]. Then, each task group could be assigned to a team. Other similar research works are focused on the information flows among actors [6],[7],[8] and the minimisation of the coordination efforts in a design project. They represent these interactions by means of DSM and they run clustering algorithms in order to build different teams. In so doing, they do not take into account the task characteristics and the actors' competencies.

Array-based clustering methods could be efficient in order to group the tasks and the actors into families simultaneously. In the second part of this section, we shortly present these methods, and particularly the ROC algorithm.

A sub-problem of team building that draws much attention is the task assignment problem. Many constraints have to be traded off against each other in team building, such as cost consideration, workload, competency level and availability of competency. In the last part, we focus our review on the task assignment with competency modelling.

2.1. Team building in design project management

Various design project management fields are presented in the research literature, such as engineering design projects, software development projects and project management in general.

In the engineering design project field, Chen and Lin [9], [10] propose an integrated methodological framework in team member assignment. Zarakian and Kusiak [11] emphasise the importance of multifunctional teams in product development. The proposed method in team formation is based on customer requirements or product characteristics. Braha [12] presents a mathematical formulation for the problem. Two main issues are addressed by this model: 1) how to specify task dependencies, and 2) how to optimally partition the tasks between a number of teams.

In the software development project field, Gronau et al. [13] develop an algorithm to propose a team composition for a specific task by analyzing the knowledge and skills of the employees. This method is based on the Knowledge Modelling and Description Language (KMDL). Tsai et al.[14] implement a critical resource diagram (CRD) and the Taguchi method, in order to select the right team members for the software development project.

In the project management field, De Korvin et al. [15] develop a personnel selection model for a multiple phase project. The "fuzzy compatibility" method is used to select potential team members for each project phase.

Durmusoglu et al. [16] propose a team building process using axiomatic design principles. After fixing the families, the selection of those team members who will process the information and the planning of their skill development are determined according to the specifications of the families. Therefore, the procedures of member selection are formed first. Then the skill development procedure is prepared to ensure maximum utilization of team members' talents.

Numerous works about team building deal with psychological and sociological competencies (personality types, leadership, communication skills, decision-making ability etc.) [9], [17], [18]. However, technical competency is the most common attribute found in team building literature in order to characterise tasks and team members [11], [14], [15],[17], [19], [20].

Fig. 1 gives the global overview of competency modelling in a classic team building approach. Authors have to characterise the competency elements (or attributes), required in performing a task or possessed by an individual so that all the members can be organised into teams. Three main elements have to be defined: task, team member and attribute. A list of tasks has to be performed in a design project. A design task can be characterised by a set of attributes (competencies). Attributes can be viewed as soft competency or technical competency. Team members come from different departments. Each department is characterised by a set of competencies that correspond to an intra-domain expertise. In the same way, a team member can be characterised by a set of attributes required in performing tasks.

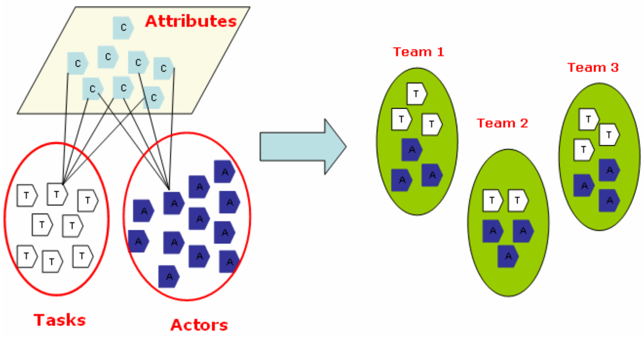

Fig. 1: Global overview of competency modelling.

2.2. Grouping tasks and actors

An array-based clustering algorithm is one of the most widely studied algorithms in the research literature. This approach is applied in the formation of manufacturing cells in order to group similar part-families on dedicated clusters of machines.

Examples of array-based clustering algorithms are as follows: ROC (Rank Order Clustering) [21], ROC2 [22], DCA (Direct Cluster Algorithm) [23], BEA (Bond-Energy Analysis) [24], [25]. Chu and Tsai [26] examines three array-based clustering algorithms - ROC, DCA, BEA - for manufacturing cell formation under different measuring criteria. Joglekar *et al.* [27] make a comparative evaluation of nine well-known algorithms for solving the cell formation problem in group technology.

The characteristic of these algorithms is that they consecutively reorder the rows and columns of a matrix according to an index until the diagonal blocks are formed. An array-based clustering approach is one of the group technology algorithms. To explain the array-based clustering algorithm, a machine-part incidence matrix **A** is developed, which consists of « 0 » or « 1 » values, where « 1 » indicates that machine i is used to process part j, 0 if not. These algorithms rearrange the rows and columns of **A** to form a final matrix **A**, where machines that process the same group of parts are close to one another, and parts that are processed by the same group of machines are close to one another. The diagonal arrangement facilitates the identification of the manufacturing cells. Once **A** is rearranged, these algorithms depend on a manual treatment in order to identify the cells.

This approach could be applied in order to solve the team building problem by using an analogy between part-machine families and task-actor families.

Tseng *et al.*[19] propose an approach to form a multi-functional project team. They think it is critical for the manager to clarify relationships between customers' requirements and engineering characteristics. Therefore, the authors adopted the ROC algorithm in order to cluster engineering characteristics (tasks) into groups. Then, team member selection is done under the group formation and organisation resource constraints.

The ROC algorithm steps are as follows:

Step 1: For each row of the part-machine matrix (or task-actor matrix), calculate the decimal weight.

Step 2: Sort rows of the matrix in decreasing order of corresponding decimal weights.

Step 3: Repeat the preceding two steps for each column.

Step 4: Repeat the preceding three steps until the position of each element in each row and column does not change.

A weight for each row i and column j is calculated as follows:

Weight for row i : $\sum_{k=1}^{n} a_{ik} 2^{n-k}$ (1)

Weight for column j : $\sum_{k=1}^{m} a_{kj} 2^{m-k}$ (2)

2.3. Task assignment with competency modelling

The original version of the assignment problem is discussed in almost every textbook for an introductory course in either management science/operations research or production and operations management. Pentico [28] proposes a survey of what appear to be the most useful variations of the assignment problem that have developed in the literature over the past 50 years. As usually described, the problem is to find a one-to-one matching between n tasks and n agents, the objective being to minimise the total cost of the assignments. In this section, we will briefly present the papers that take the competency constraint into account.

Caron et al. [29] take an interest in the classic assignment problem recognizing agent qualification. In their work on a particular version of the assignment problem with side constraints, Caron et al. [29] use a mathematical model for a variation of the classic assignment problem in which there are m agents and n tasks, not every agent is qualified to do every task, and the objective is utility maximization.

Campbell and Diaby [30] propose an assignment heuristic for allocating cross-trained workers to multiple departments. This paper is concerned with solving a mathematical programming problem that models a multi-department, labor-intensive service environment, such as that faced by hospital nurses. Factors to consider in making such allocations include demand levels in various departments and the capabilities of available workers.

Eiselt and Marianov [31] propose a model for the assignment of tasks to employees when several goals are to be considered, and when there are constraints regarding employees' capabilities. They define a skill space, in which each dimension represents a skill or ability. Each employee can be mapped into this space, his/her position representing the level acquired in each skill. Similarly, tasks can also be mapped into the skill space, and their position will represent the required level in each skill. After feasible task assignments are determined, tasks are assigned to employees.

Wu [32] provide a framework for a fuzzy linear programming model for the function management division dealing with the manpower allocation problem within matrix organization. The proposed model reveals how the function management division seeks a minimised cost and satisfies the requirements of functional departments under limited manpower and project cost.

Peters and Zelewski [33] develop a model for the assignment of employees to workplaces. Employees will be assigned to workplaces according to their competencies and preferences to ensure that motivated employees carry out tasks effectively and efficiently. Two-goal programming models are introduced with input valuation using the Analytic Hierarchy Process (AHP).

2.4. Task assignment with dynamics of competency

The dynamics of an employee's competency directly depends on the tasks that he/she has been assigned. Assigning a task to an individual may develop or at least maintain his/her acquired skills. The competency deterioration (or skill fade / skill decay) can occur when an individual has not been assigned for some time.

Boucher et al. [34] indicated that competencies can be seen from three distinct views: static, functional and evolutionary. The static view concerns identification, structuring and evaluation of competencies. The functional view concerns the mechanisms of competency mobilization in a working context where the goal is to make an efficient use of available competencies. The evolution view deals with the notion of dynamics of competency. Our team building approach developed in this paper is to provide a team building solution based on functional and evolutionary views.

The competency dynamics constraint is becoming increasingly challenging for task assignment problems. However, there are still very few research works providing solutions to this issue. Recently, Sayin and Karabati [35] propose a framework to solve the worker assignment problem while incorporating a learning and forgetting curve in a decision model. The authors assume that, in an on-the-job training environment, whenever a worker is assigned to a department, his/her skills in that particular department improve according to his/her individual learning curve. Their framework is experimented in manufacturing and service settings for assigning cross-trained workers across departments. The computational experiments suggest that incorporating the skill improvement function explicitly in the model results in significant improvement in the total skill level of the workforce and thus leads to more effective worker assignments.

2.5. Summary of reviews and observations

As reviewed above, this literature analysis concerning team building can be summarised as follows:

(1) In spite of the importance of team building in project management, there is still limited research to provide analytical solutions for multidisciplinary team building.

(2) The team building problem may be solved in two distinct ways. The most largely studied approach concerns task assignment and very few researches propose a task-actor clustering.

(3) Task assignment provides the optimised solution in order to select the right person for the right task under several constraints given by the project manager. The competency dynamics has been rarely studied.

3. Multidisciplinary team building method

The proposed team building comprises the competency modelling, the task-actor clustering and the competency dynamics-based task assignment. First, the competency modelling is based on the calculation of a competency matrix that represents the actors' competency level for a given list of tasks. Second, the task-actor clustering is an important step due to the growing complexity of design projects; the tasks and the actors could be able to form into mutual exclusive blocks through the ROC algorithm. Third, a competency dynamics-based task assignment model i to minimise the project costs.

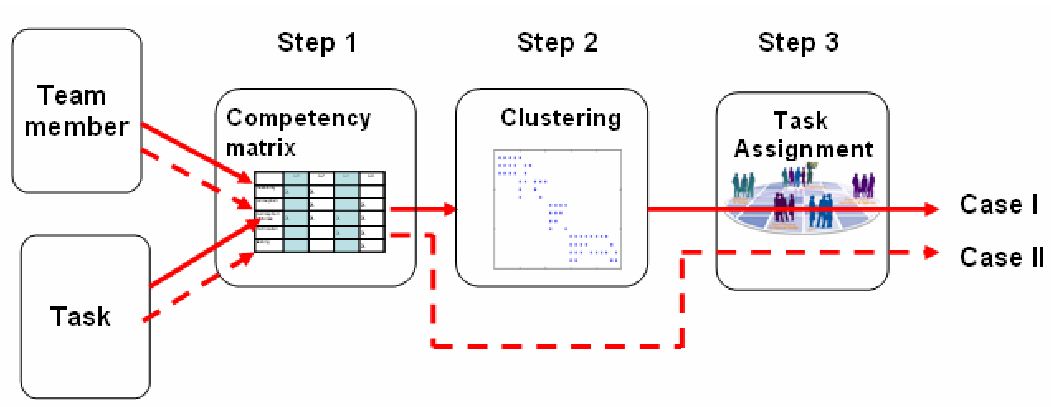

Fig. 2: Team building approach

This approach is split up into three main steps (Fig. 2). First, we explain how to generate a competency matrix. Second, we present an algorithm in order to group task/team members into families using an array-based clustering algorithm, we adopt the ROC clustering algorithm to cluster tasks and actors into groups. This clustering step is inspired by Tseng *et al.*[19]. Third, we show how to solve the task assignment problem by means of a binary integer programming model. In section 5, we conduct our experiments in two different cases. We apply all the three steps in case I, but in case II, we will not apply the clustering step (step 2). We will discuss the interests of these two cases in § 5.5. In the following part, we present each step in more detail.

3.1. Computing the competency matrix

A competency matrix is a matrix that represents the relationships between a set of tasks and a set of actors. It can be interpreted as a compatibility indicator between these two sets. The matrix has one row for each *task* and one column for each *actor (or team member)*. The entry in row x and column y is between 0 and 1. The value is close to 1 if x and y are strongly interrelated and 0 if they are not.

The calculation of a compatibility indicator can also be seen as a competency level for selecting the appropriate candidate by measuring the similarity distance between an acquired skill set and a required skill set. Numerous distance measures have been mentioned in research literature - for example, the Hamming distance used in the personnel selection [36]. The compatibility indicator indicates the relation between considered task and actor. It corresponds to the acquired competency level of the actor j relating to task i.

We identify five steps to generate a competency matrix:

- Identify relevant attributes to characterise both task and team member.
- For each task, evaluate the required performance for each attribute
- For each team member, evaluate the performance level for each attribute.
- Calculate a compatibility indicator between task and team member (by using equation 3).
- Generate a competency matrix.

Let T, C and **A** denote ordinary non empty sets of task, attribute and actor, respectively.

Let R^1 be a relation from T to C and let R^2 be a relation from C to **A**. Then $(R^1 \circ R^2)$ is a relation from T to **A**.

Let us denote *i*=index of tasks (*i*=1…I), *j*=index of actors (*j*=1…J), *k*=index of attributes (*k*=1…**K**). $(R^1 \circ R^2)$ is the compatibility indicator between the task *i* and the actor *j*. R^1_{ik} = level of attribute *k* required by the task *i*, R^2_{kj} = level of attribute *k* acquired by the actor *j*.

$$R_{ij} = R^1_{ik} \circ R^2_{kj} = 1 - \frac{\sum_{k=1}^{K} \max(0, R^1_{ik} - R^2_{kj})}{\sum_{k=1}^{K} R^1_{ik}} \tag{3}$$

In calculating this compatibility indicator, our method points out the difference between overcompetency case for each attribute $(R^1_{ik} < R^2_{kj})$ and undercompetency case for each attribute $(R^1_{ik} > R^2_{kj})$. Overcompetency and undercompetency are the comparison between two types of attribute level: acquired and required. For each attribute, overcompetency indicates that the acquired attribute level of a team member is higher than the required attribute level of a task, and vice versa for the undercompetency case.

3.2. Identifying task / team member families by clustering method (optional step)

The clustering algorithm used in our approach identifies task groups (intra-domain expertise) and actor groups. The clustered task and actor groups show us the global image of existing intra-domain expertise in an organization.

We adopt here a ROC algorithm (see equation ((1)-(2)). The *ROC clustering algorithm* will transform the task-actor matrix into task/actor families.

3.3. Assigning tasks to team members

The task assignment problem contains a group of tasks (or missions) to be accomplished. Section 4 gives more detail about the proposed binary integer programming model.

4. Mathematical formulation for task assignment

The objective is to find one suitable candidate for each task which minimises the total project costs. Two cost types are used in the proposed cost function: the employee's salary and the training cost (related to the expert's salary). The expert's role is to assist the team member in acquiring the competency.

We assume that every task has the same processing time H. This assumption will simplify the model since no workload constraint has to be considered.

4.1. Learning curve for competency development

The team member cost depends on team members' salaries and task durations (H). Likewise, we assume that the training cost depends on experts' salaries and training durations (ΔT). Training duration (ΔT) depends on the competency gap, which is the difference between the required competency level and acquired competency level of the team member. If the team member has large competency gap, the expert has to use more training time in order to help team member to reach the required competency level. .

A learning curve inspired by Wright [37] will be applied in order to calculate the training duration time (ΔT). This learning curve is simply demonstrated by an exponential function (Fig. 3), which is described in equation (4).

$$y = c \times x^b \tag{4}$$

Variables :

- y = The cumulative learning time in order to reach a given (required) competency level
- x = The cumulative level of acquired competency (this value varies from 0 to 1)
- c = The duration necessary for reaching the competency level 1, that means, becoming an expert for the considered task (for instance, c=5 in Fig 3).
- b = The slope of the function (in a log-log scale)

The values of c and b may depend on the considered task. The learning difficulty of each task may be different. Fig. 3 gives an example of a learning curve for a specific task that has c=5 and b=2.3. In this paper we assume that c and b have the same values for every task.

The learning curve shape is justified by the fact that the higher the cumulative level of competency, the more difficult it is to reach a higher required competency level, and the higher the training time.

We use equation (5) to calculate the training duration (ΔT_{ij}). ΔT_{ij} represents the time dedicated by the expert for helping team member j to attain the competency level required by task i . No training time is necessary in case of overcompetency.

R_{ij} is the compatibility indicator (between a task i and a team member j), which has the same meaning as the cumulative level of acquired competency level before task assignment.

RQ_i is the competency level required by a task, which represents the cumulative level of acquired competency level when the task is done. $y_1 = c \times RQ_i^b, y_2 = c \times R_{ij}^b, \Delta T_{ij} = \max(0; y_1 - y_2)$.

$$\Delta T_{ij} = \max(0\,;\, c \times (RQ_i^b - R_{ij}^b)) \tag{5}$$

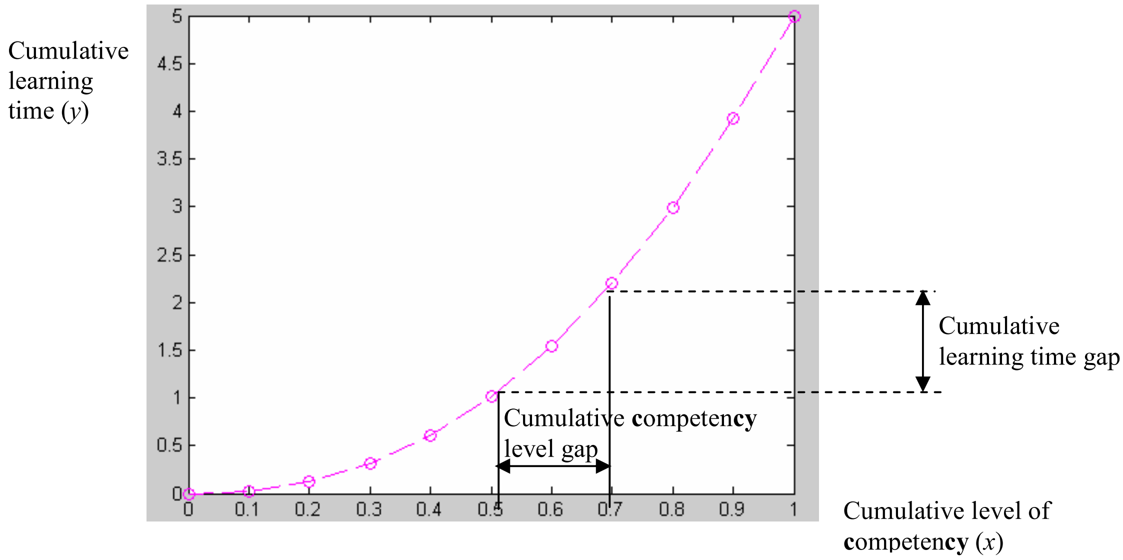

Fig. 3: Example of a learning curve concerning a specific task (c=5, b=2.3)

4.2. Binary integer programming model

Assumptions:

- The dynamics of competency are in operation while a task is executed. The competency level of an individual will increase (depending on the learning curve function) during a task execution. The regression model of competency is not considered in this paper.
- The list of tasks is provided. There is no extension time for the execution of each task due to the competency deficiency. ΔT_{ij} includes the training time during the task execution (proceeding time H) and a possible pre-training period. The pre-training starts before the beginning of the project.

Variables:

- i : index for multidisciplinary tasks (i=1…I)
- j : index for multidisciplinary actors (j=1…J)
- x_{ij} : decision variable
- **Mi** : minimum competency level required to accept the assignment
- d_{ij} : assignment acceptance variable (this variable corresponds to a minimum competency level required to accept the assignment)
- Sj : employee's salary
- ST : experts' salary
- ΔT_{ij} : time taken to attain the competency level required by task i

The mathematical model is formulated as follows:

$$\text{Minimise : } F = \sum_{i}^{I}\sum_{j}^{J}(S_j + ST \times \Delta T_{ij}) \times x_{ij} \qquad (6)$$

Subject to constraints:

$$\forall i = 1...I; \quad \sum_{j=1}^{J} d_{ij} \times x_{ij} = 1 \tag{7}$$

$$\forall j = 1...J; \quad \sum_{i=1}^{I} d_{ij} \times x_{ij} \leq 1 \tag{8}$$

$$\forall j = 1...J; \quad \forall i = 1...I: \quad x_{ij} = 0 \ or \ 1 \tag{9}$$

The objective function of the model ((6)-(9)) minimises the total salary cost of the multidisciplinary teams, $x_{ij} = 1$ if agent i is assigned to task j, 0 if not, $d_{ij} = 1$ if actor i is qualified to perform task j, 0 if not. We can assume that a team member is qualified ($d_{ij} = 1$) when his/her compatibility indicator R_{ij} is higher than a given rate M_i, depending on the considered task. Constraint (7) implies that each task will be assigned to one person only. Constraint (8) demonstrates that one person can be allocated to one task only.

5. Illustrative example

A design project with seven tasks requiring ten attributes is used as an illustrative example. The design department has eleven members; and each member possesses a set of different attributes with different performance levels.

We give here an example of a task in a mechatronical product development project. The task "develop the architecture of a mechatronical system" requires a set of skills (considered as attributes) such as: to know mechanics (0.7), to know thermodynamics (0); to know control systems (0.8); to know electronics (0.5); to know how to use CAD system (0.7), Etc. An actor's competency can be characterised by the same set of skills.

5.1. Choice of parameter values

- Coefficients b and k have the same values for every task, 1.2 and 5, respectively.
- **M_i** equals 0.4 for each task i
- The experts' salary is 3500 euros per period of time (H).
- The employee's salary is given in Tab. 1.

Tab. 1: Employee's salary (S_j)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
salary	2070	2500	2610	2400	2700	2300	2800	2150	2250	2200	1620

In the first part, the creation of a competency matrix is presented. Then, two optimisation cases are demonstrated in the last two parts consecutively.

5.2. Creation of competency matrix

- First, we calculate the compatibility indicator from task-attribute matrix (Tab. 2) and actor-attribute matrix (Tab. 3), and then we obtain the Competency matrix in Tab. 4. The values in the competency matrix (compatibility indicator) are calculated by equation 3.

Tab. 2: Task-attribute matrix (R^1)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
T1	0,8	0	0,2	0	0	0,9	0	1	0	0
T2	0	1	0,7	1	0	0	0,6	0	0,3	0
T3	0	0	0	0	0,9	0	0	0	1	0
T4	1	0	0,1	0	0	0	0	0,7	0	0
T5	0	0,8	0	1	0	0	0,4	0	0	0,1
T6	0,2	0,3	0	0	0	1	0	0,8	0	0
T7	0	0	0,1	0,1	1	0	0	0	1	0,7

Tab. 3: **Ac**tor-attribute matrix (R^2)

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**
C1	0,7	0,1	1	0,4	0	0,2	0	0,6	0	0,65	0,4
C2	0	0,65	0	0,9	1	0	0,9	0,1	0	0	0
C3	0	0	0,3	0,2	0,4	0	0,6	0	0	0,2	0
C4	0,3	0,4	0	0,7	0,7	0	0,8	0,2	0	0,1	0
C5	0	0,7	0	0	0	0,9	0	0	0,9	0	0,1
C6	0,7	0	1	0	0	0	0	0,67	0	0,7	0,5
C7	0	0,9	0	0	0	0,6	0	0	0,67	0	0,2
C8	0,6	0	0,6	0	0,2	0	0,1	0,71	0	0,6	0,59
C9	0	0,5	0	0	0	0,7	0	0	0,6	0,1	0
C10	0	0,7	0	0	0	0,6	0	0,1	0,8	0	0

Tab. 4: Competency matrix (R_{ij})

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**
T1	0,69	0,03	0,86	0,21	0,14	0,07	0,10	0,68	0,00	0,74	0,51
T2	0,08	0,54	0,08	0,50	0,58	0,25	0,64	0,08	0,25	0,11	0,06
T3	0,00	0,63	0,00	0,00	0,00	0,84	0,00	0,00	0,79	0,05	0,05
T4	0,72	0,06	0,94	0,28	0,17	0,11	0,11	0,72	0,00	0,75	0,55
T5	0,13	0,67	0,00	0,65	0,65	0,22	0,70	0,17	0,22	0,04	0,09
T6	0,65	0,17	0,78	0,22	0,22	0,09	0,17	0,73	0,00	0,65	0,56
T7	0,03	0,69	0,03	0,07	0,07	0,76	0,07	0,07	0,76	0,10	0,03

- Second, the training cost is calculated (ΔT_{ij} * expert's salary).

5.3. Case I : Local optimization with clustering algorithm

The principle of optimization with clustering algorithm is that the task assignment will be done within each group. After the clustering algorithm is applied to a competency matrix (R_{ij}), we obtain three separate task-member groups. We note that, after using the clustering algorithm, project teams will be formed automatically. Since we have more than one candidate for each task, task assignment still needs to be done. We adopt mathematical programming here to solve the task assignment problem.

Step 1: apply the clustering algorithm to competency matrix

Step 2: solve the task assignment problem (equation ((6)-(9))) for each cluster.

Tab. 5: Clustered Competency matrix (R_{ij})

	A3	A10	A8	A1	A11	A4	A5	A7	A2	A6	A9
T4	0,94	0,75	0,72	0,72	0,55	0,28	0,17	0,11	0,06	0,11	0,00
T1	0,86	0,74	0,68	0,69	0,51	0,21	0,14	0,10	0,03	0,07	0,00
T6	0,78	0,65	0,73	0,65	0,56	0,22	0,22	0,17	0,17	0,09	0,00
T2	0,08	0,11	0,08	0,08	0,06	0,50	0,58	0,64	0,54	0,25	0,25
T5	0,00	0,04	0,17	0,13	0,09	0,65	0,65	0,70	0,67	0,22	0,22
T7	0,03	0,10	0,07	0,03	0,03	0,07	0,07	0,07	0,69	0,76	0,76
T3	0,00	0,05	0,00	0,00	0,05	0,00	0,00	0,00	0,63	0,84	0,79

The task assignment algorithm will run three times; the optimization will be done to each group separately (Tab. 5). The result from this task assignment will sustain the intra-domain expertise because actors will always be assigned only to the tasks in the same group. This solution doesn't guarantee the lowest cost benefit but it preserves the competency dynamics within groups. For RQ=0.8, the total cost of the assignment that we obtained is 25997 euros. The total costs obtained by the task assignment in each group are 9342, 11278, 5377 euros, respectively. The assignment solution is given in Tab. 6.

5.4. Case II : Global optimization without clustering algorithm

This case deals with the task assignment problem solving by optimizing all tasks and team members without using clustering algorithm. This solving method is the typical case for task assignment problem. With the same data as in case I, we optimise by using the mathematical model ((6)-(9)). We obtain the results in Tab. 6. For RQ=0.8, the total cost in case II is 25676 euros, lower than the total cost in case I. However, the results for competency increase (difference between the total sum of competency levels after and before assignment decisions) are better for case I than case II.

Tab. 6: Task assignment results

	Random solution	Optimised solutions					
	RQ=0.8	RQ=0.8		RQ=0.7		RQ=0.6	
Task		Case I	Case II	Case I	Case II	Case I	Case II
1	10	3	3	10	10	8	10
2	5	7	7	7	7	7	7
3	9	6	6	6	9	6	9
4	3	10	10	1	1	1	8
5	7	4	2	4	2	4	4
6	8	8	8	8	8	10	1
7	6	9	9	9	6	9	6
Cost for Group 1	-	9342	-	6420	-	6420	-
Cost for Group 2	-	11278	-	7313	-	5200	-
Cost for Group 3	-	5377	-	4550	-	4550	-
Total cost (euros)	26868	25997	25676	18283	17962	16170	16170
Competency increase	0.5	0,47	0.45	0.11	0.09	0	0

5.5. Discussion

The former solution (case I) encourages the cost benefit and the development of domain expertise, whereas, the latter solution favours the cost benefit but can jeopardise the development of domain expertise. From the task assignment result in Tab. 6, RQ=0.8, task 5 is assigned to actor 4 in the clustering case and to actor 2 in the non-clustering case. In the clustering case, actor 2 can't be assigned to task 5 because actor 2 doesn't share the same task group. The non-clustering case shows that selecting actor 2 can decrease the project cost, but he/she might have the difficulty to maintain his/her intra-domain level. Therefore, the project leader has to find a trade-off between these two assignment criteria.

6. Conclusion and future work

The approach presented in this paper provides a framework for multidisciplinary team building in a design project. It can be successfully used in the early stages of product design to characterise the team members' competencies and to assign tasks under various constraints, i.e., qualification, competency development and salary.

Local task assignment with a clustering algorithm can maintain employees' expertises more efficiently than global task assignment. However, if the assignment objective is to increase the employees' polyvalence, the global task assignment can provide a better solution. Moreover, a local task assignment with a clustering algorithm can be used for large-scale projects in which strategic competencies objectives are well defined and necessary to be attained.

The model presented in this paper provides a framework for team building in a design project. The major advantage of this approach is that it can be easily modified and extended to incorporate some other factors, for example, "soft factors"' ,i.e., inter-relational capabilities, leadership, personalities of team members, etc., that are important in team building.

In order to assist the companies in achieving their strategic competency objectives, the systematic multi-period team building approach needs to be studied. This work can be a first step towards multi-period team building to help the project managers managing their human resources in order to attain the long-term competency goal. Such a multi-period team building model will provide the ability to look ahead into future periods while performing task assignments.

Other extensions are to integrate workload constraints, a regression curve of competency and a multi-criteria formulation in the task assignment model.

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